

# WIRELESS ENERGY TRANSFER

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## INTRODUCTION

### Problem

Phones are now an integral component in the daily lives of people. Smartphones give access to movies, internet, and even books. This versatility and increased use can also lead to a shorter battery life. A phone with video viewing capabilities will be a heavy load on the unit's battery. With phones utilizing 3G and 4G technology, even heavier demands are placed on the battery. Utilizing all of these capabilities on a smartphone gives the device an average of seven hours of battery life [1]. As technology improves even further to provide for a larger entertainment experience on the phone, this could also lead to further battery degradation if the current battery situation isn't addressed. To have a fully operational phone throughout the day, a wireless energy transfer car charger can be utilized.

### Solution

The solution starts with a car. For a lot of people, driving in their car is an integral part of everyday life. The average US driver is in their vehicle for 55 minutes a day [2]. With smartphones such as the iPhone taking around two hours to charge, this creates the perfect opportunity to provide for extra charge during the day [3]. Although it will not completely charge the phone, it will help keep the phone operational by keeping it charged steadily throughout the day. With a wireless energy system, it would be possible to charge a phone without having to make the effort to connect the phone to a charger once in a car. A pocketed phone will charge

wirelessly through a transmitter coil under the seat. No work or thought is needed by the user to charge the phone after initial setup. The energy for the charger is provided by the car battery.

## **BACKGROUND**

### **Goal**

The aim of this project is to create the wireless energy transfer system that will allow future systems to wirelessly charge phones. The goal is to obtain an efficiency of 70% at a distance of 1 ft. 70% is the minimum requirement for the Qi low power standard, and a foot would give sufficient range for user interaction [4]. The Qi low power standard is a set of wireless power specifications that companies have to follow in order to gain the recognition of the Wireless Power Consortium. Overall, these goals would make it possible for a charging system to be efficient, and also give the system a good charging radius. A product that uses this technology would be a working system where someone can sit in their car and have their phone charge requiring a conscious effort to initiate the charging.

### **Justification**

In 2010, Android and iPhone users spent an average of 80 min/day using mobile apps alone [5]. With the inclusion of video and constantly improving mobile telecommunication standards, smartphones need an extended charging period throughout the day to keep them operational.

Low batteries limit the user's capabilities on the phone. A system that is installed in the car will constantly charge the phone without the user's effort. This

will reduce low battery situations, since the phone can be charging every time a user drives their car.

Currently, when phone users are unable to reach their home chargers, the only solution is to use a car charger. Plugging a phone into a car charger when entering car, and unplugging it when leaving becomes an unwanted, but necessary, task for many phone users in order to maintain an acceptable charge. A wireless energy transferred system will remove the need for a charger, and will simply start charging as the user enters the vehicle and sits down. This is an excellent time to release such a product with wireless energy capabilities.

### **Safety**

With the small amount of magnetism involved, there aren't any known problems caused by the wirelessly transferred energy. Studies done with much more powerful magnets have shown not to have produced any potential harm in the human body [6]. The wireless energy system uses common materials, such as copper wire and capacitors that cause no danger to humans. The system does no extra harm itself, as it is housed inside of a vehicle.

### **Power Usage**

The system uses around 5W, provided by the car battery, to charge a phone that requires 3.5W to charge. Since the energy is transmitted wirelessly, it is trading



off efficiency for practicality. The charger uses the car battery to charge the phone battery, which causes some pollution compared to a solar charger.

### **Potential**

If the manufacturer outsourced all of its parts, then the total cost of the system would be around \$80, and it could retail for \$110 or more. The cost of the system would decrease if the seller created their own parts. Being an item of luxury, the price can be justified by its practicality. Automotive maintenance shops could also charge for installation. The lifetime of the product is very large because there are few moving parts, and the system only serves to transfer power; leaving little probability of any immediate problems. There are no operation costs, besides fuel used to charge the battery, but maintenance/replacements of the receiving coil or transmitting coils may arise.

### **Investment**

The people that would be involved in the application of this product could most likely become a small startup company. Since a wireless energy powered car charger is a relatively new concept for a product, it would be a great opportunity for a new company to build a business around.

A larger company could also pick up this product. They would have larger potential for profit, since they will be able to machine the charging system

themselves. A wireless energy transfer car charger would make a great addition to the product line of an electronics company.

## REQUIREMENTS

### Wireless Energy Transfer

The plan is to create a system that can transmit power wirelessly. This is achieved by connecting a power source to an inductive coupling system that uses magnetic fields to transfer the energy through air. The coupling system involves a transmitting coil component  $L_1$  sending energy to a receiving coil component  $L_2$ . This is done by sending an energy signal through the  $L_1$  coil, and creating a magnetic field  $B$ . The  $L_2$  coil then creates an energy signal using the magnetic field. The coupling system is shown in Figure 1 below.

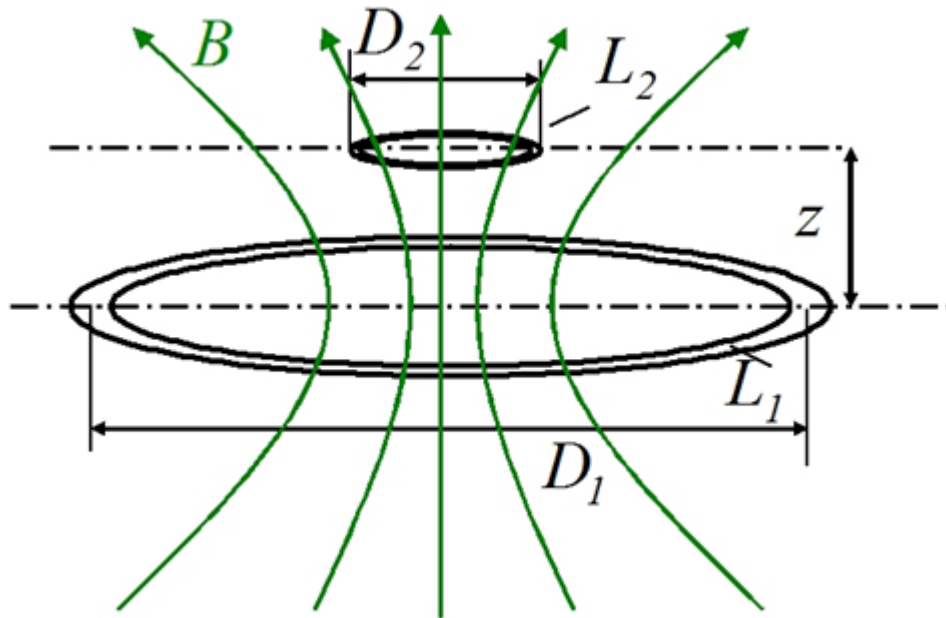


Figure 1: Inductive Coupling System [4]

The system's efficiency is based on the size ratio  $D2/D1$  of the two coils and the distance between the two coils ( $z$ ). As the ratio  $D2/D1$  decreases, the efficiency will decrease. As the distance between the two coils increases, the efficiency also decreases.

The power source is connected to the first two transmitting coils, and then will wirelessly transfer the energy to the receiving two coils. This energy will then go towards charging the battery of a phone, which would be the load.

### **Efficiency**

One of the main problems of inductive coupling is the efficiency output. A way that may increase the efficiency is to use a newly invented system that uses four inductive coils instead of just two to increase the efficiency and range [7]. Each of the transmitting and receiving coils each have an additional transmitting and receiving coil attached to it that are identical to their counterpart, except being only half the size. In theory, the two coils work together to transmit magnetic waves to the boosted receiver, while using the same current that a single coil system would. The  $D2/D1$  ratio, as well as the coil distance  $z$ , affect the efficiency as well, and must be considered when designing the system.

### **Transmitting/Receiving Coils**

Since the receiving coil will eventually be attached to the phone, the size of the coils will have to be decided by the size of the phone. Typical phones, such as the

iPhone 4 and Droid 2, only have their small side length of 2.31'' and 2.39'', respectively [8] [9]. That's why the receiving primary coil will be built to have a radius of about 2.25 inches in diameter, and the secondary coil half the size. The receiving coil should not have a diameter that is less than 0.3 the size of the transmitting coil, otherwise the efficiency will drastically go down. This will make the primary transmitting coil have a diameter of 7.5 inches, with the secondary coil half of that size.

## DESIGN

### The System

The design of the project is to take the energy from a power source and allow it to be transferred wirelessly. The receiving AC will then be converted to DC for charging. The main part that the design needed is the capability to transfer the energy wirelessly. Figure 2 shows the block diagram of the wireless system.

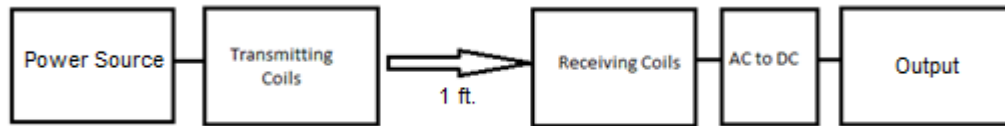


Figure 2: Block Diagram of the System

### Power Transfer

The AC power source will be transmitted wirelessly through resonant inductive coupling. The inductance of the inductor can be measured, and then coupled with a capacitor to be tuned to a frequency. The frequencies can be matched by both the transmitting and receiving coils, allowing them to communicate together much more efficiently. Figure 3 below shows the circuit of the inductive coupling system.

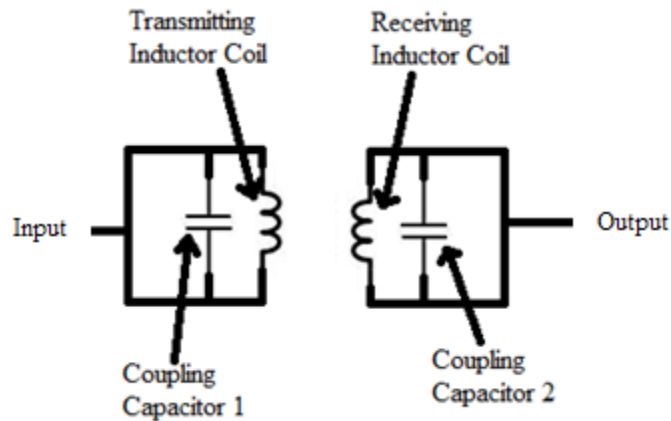


Figure 3: Wireless Power Transfer Circuit Design

After the receiving coil obtains the AC, it will be converted back to DC using a full wave rectifier and regulator circuit. This will give the phone the right amount of energy it needs to charge.

### Efficiency

For efficiency, various coils were created to test which configurations produced the best efficiencies. A four-coil system has been implemented that used two connected coils on the transmitting size, one half the size of the other. Other two-coil systems were also implemented for experimentation. In order to obtain maximum efficiency, the transmitting to receiving coil ratio would be 1:1. The goal is to find an appropriate ratio that still provides appropriate efficiency, while also giving a larger coil-to-coil distance. This is done by making the transmitting coil larger than the receiving coil, but not so large to decrease the efficiency too much. To maintain an efficiency above 70%, while gaining a larger  $D_1$ , a coil size ratio  $D_2/D_1$

of 0.3 was chosen. The larger  $D_1$  is useful for increasing the size of  $z$ , while maintaining efficiency. The 0.3 ratio was obtained from Figure 4 below, which provided information about the efficiencies of various  $D_2/D_1$  coil ratios.

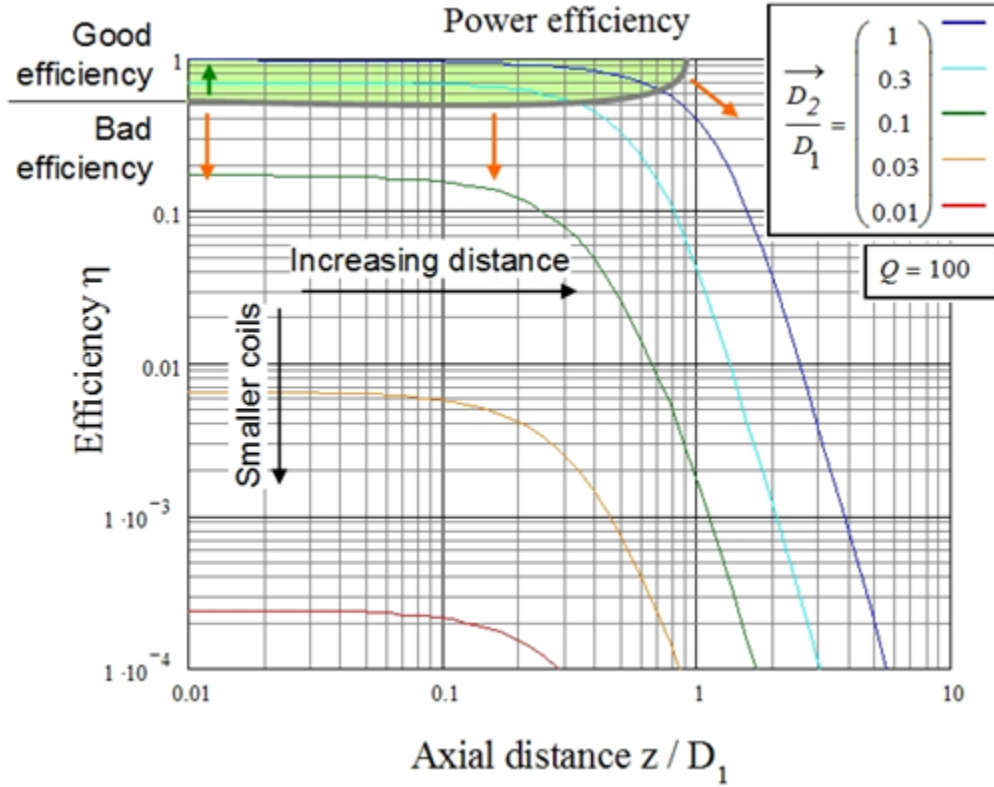


Figure 4: Power efficiency vs. distance graph based on coil sizes [4]

The graph was obtained from calculated values of coils with a quality factor of 100.

### Coil Inductors

With the transmitting coil having no size constraints, the constraints come from the size of the phone. With the iPhone 4 having a width of 2.31 in, being the



general size of a smartphone, the receiving coil design has a 2.25 in. diameter. So, with a set receiving coil size, a transmitter coil maintaining the 0.3 coil size ratio would be 7.5 inches in diameter. Although the 0.3 line trails with increasing distance, the four-coil system should improve the efficiency with longer distances.

### Capacitors

In order to choose the correct capacitors with which to couple the coils with, the following formula must be used:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The frequency can then be found with a given capacitor coupled with an inductor coil, or the frequency can be chosen and a capacitor calculated. The other capacitor value can then be found for the other coil using the formula:

$$C = \frac{1}{4\pi^2 f^2 L}$$

The capacitors will then be connected in parallel with the inductors to create a resonant coupling.

The quality factor is based on the ratio of the apparent power to the power losses in a device [4]. As the quality factor increases, the power losses decrease. Building useful coils require them to have a quality factor Q around 100 and above. The formula for quality factor is:

$$Q = \frac{\omega L}{R}$$

If the quality factor is too low, the coil material or the coil design could be useless, and should be changed. The quality factor can also be increased by increasing the frequency, which will decrease the capacitor values.

## **CONSTRUCTION**

### **Transmitting 20N Vertical Magnet Wire Coil**

A 7.5 in. (19cm) transmitting coil with 10 turns, wound with a 9.5cm secondary coil with 10 turns was created out of 22-guage enameled magnet wire (labeled Trans. 20N V Magnet Wire on tables). The turns were wound vertically with respect to each loop, which gave it a height of 0.8cm.

### **Receiving 20N Vertical Magnet Wire Coil**

A 2.25 in. (5.8cm) receiving coil with 10 turns, wound with a 2.9cm secondary coil with 10 turns was also created out of 26-guage enameled magnet wire (Rec. 20N V Magnet Wire). The turns were also vertical, which gave it a height of 0.4cm.

### **Transmitting/Receiving 10N Vertical Magnet Wire Coils**

A 10 turn, vertically wound, 19cm transmitting coil was made with 22-guage enameled magnet wire for testing (Trans. 10N V Magnet Wire). This coil was made without the secondary coil to observe the benefits of the four-coil system. A 10 turn, vertically wound, 5.8cm receiving coil was also made with 22-guage enameled magnet wire to match the transmitting coil (Rec. 10N V Magnet Wire).

### **Transmitting/Receiving 5N Horizontal Magnet Wire Coils**

To test varying coil constructions, a pair of 5 turn, horizontally wound, 5.8cm coils were made with 22-guage enameled magnet wire to test the horizontal system, and how similar-sized coils transmit energy (Trans/Rec. 5N H Magnet Wire).

### **Transmitting(1,2)/Receiving 10N Horizontal Copper Hook Wire Coils**

A 19cm, 10 turn, horizontally wound transmitting coil was created with 22-guage copper hookup wire to test out a different inductive material (Trans.(1) 10N H Copper Hook Wire 1). Two 10 turn, horizontally wound, 5.8cm coils were also made with 22-guage copper hookup wire to test with the transmitting coil, and with each other (Trans.(2) 10N H. Copper Hook Wire 2, Rec. 10N H. Copper Hook Wire).

### **Transmitting/Receiving 5N Horizontal Tinned Copper Bus Coils**

I also created some prototype coils made of tinned copper bus wire, made as 5.8cm, 5 turn, horizontally wound receiving coils for further testing of efficiencies on different inductive materials (Trans./Rec. 5N H Tinned Copper Bus).

### **Transmitting/Receiving 5N H Copper Wrap Wire Coils**

Two more prototype coils made of copper wrapping wire were created, made as 5.8cm, 5 turn, horizontally wound receiving coils (Trans./Rec. 5N H Copper Wrap Wire). This was done to further test alternate inductive materials.

## TESTING

### Setup

In lab, transmitting coils are tested individually with a receiving coil, coupled together with capacitors. An input AC wave was introduced using a Function Generator, and the input/output signals were sent to the oscilloscope to measure the voltage. To measure the current, the multimeter was connected in series with either the input or output, and the AC current was measured. A small valued resistor was then connected to the load to test the efficiency ratios of the system. Figure 5 shows the general setup of coil testing.

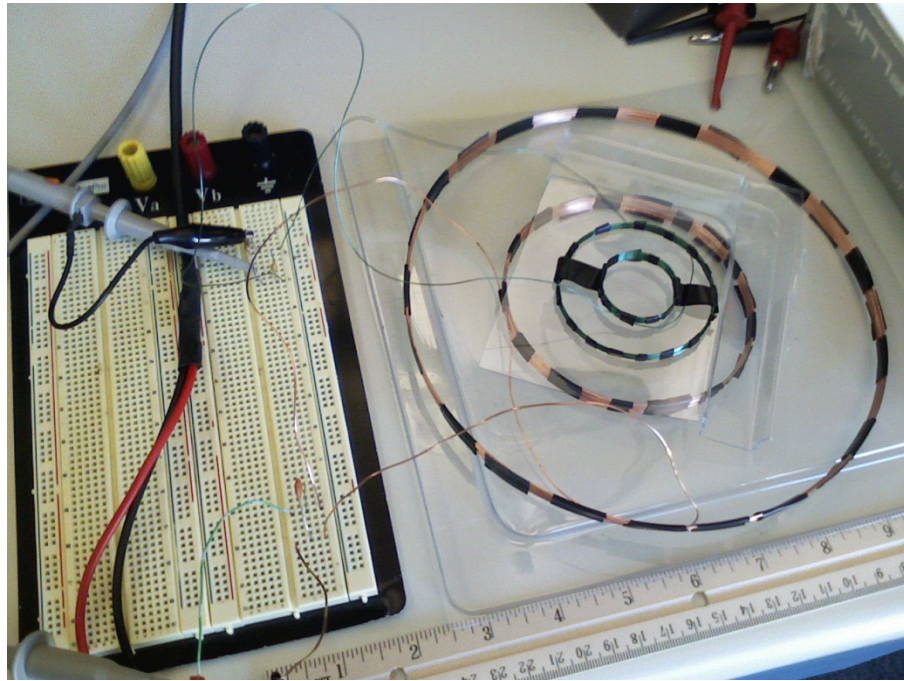


Figure 5: Resonant Inductive Coupling Setup

## Coil Measurements

Each of the coil's inductance and resistance were measured for coupling and quality factor calculations. Below is a table of the measured values of the coils, and their calculated quality factors given the calculated testing frequencies.

Table 1: Coil measurements and Q data

Coil	Inductance(mH)	R( $\Omega$ )	Coupled Frequency(Hz)	Quality Factor
Trans. 20N V Magnet Wire	0.0874	0.607	37000	33.47374736
Rec. 20N V Magnet Wire	0.0263	0.625	37000	9.782668196
Trans. 10N V Magnet Wire	0.13	1.25	61000	39.86052759
Rec. 10N V Magnet Wire	0.077	0.275	61000	107.316805
Trans. 5N H Magnet Wire	0.0598	0.206	164000	299.1284221
Rec. 5N H Magnet Wire	0.0728	0.23	164000	326.1574175
Trans. 10N H Copper Hook Wire 1	0.1685	0.603	58000	101.8334494
Trans. 10N H Copper Hook Wire 2	0.112	0.234	121000	363.8877234
Rec. 10N H Copper Hook Wire	0.0942	0.229	58000	149.9074727
Trans. 5N H Tinned Copper Bus	0.1727	0.159	339000	2313.528105
Rec. 5N H Tinned Copper Bus	0.1726	0.223	339000	1648.600757
Trans. 5N H Copper Wrap Wire	1.6377	0.986	93000	970.5552228
Rec. 5N H Copper Wrap Wire	1.3305	0.923	93000	842.3178318

## Calculations

The data below shows the different coils tested with different resistor values, and their respected efficiencies.

### Trans./Rec. 20N V Magnet Wire

1 Ohm

$$V_{in} = 8 V_{pp}, I_{in} = 0.01140 A_{rms}$$

$$\Rightarrow P_{in-avg} = V_{rms} * I_{rms} = 8 V_{pp} / (2 * \sqrt{2}) * 0.01140 A_{rms} = 0.03224 W$$

$$V_{out} = 0.1175 V_{pp}, I_{out} = 0.03494 A_{rms}$$

$$P_{out-avg} = 0.2 V_{pp} / (2 * \sqrt{2}) * 0.03494 A_{rms} = 0.00145 W$$

$$Efficiency = \frac{P_{out-avg}}{P_{in-avg}} \times 100 = 0.00145 W / 0.03224 W = 4.50\%, \quad Efficiency = 4.50\%$$

8 Ohm

$$V_{in} = 8 V_{pp}, I_{in} = 0.01533 A_{rms} \Rightarrow P_{in-avg} = 0.04336 W$$

$$V_{out} = 0.7625 V_{pp}, I_{out} = 0.03402 A_{rms} \Rightarrow P_{out-avg} = 0.00917 W, \quad Efficiency = 21.15\%$$

#### Trans./Rec. 10N V Magnet Wire

1 Ohm

$$V_{in} = 8 V_{pp}, I_{in} = 0.02045 A_{rms} \Rightarrow P_{in-avg} = 0.05784 W$$

$$V_{out} = 0.1910 V_{pp}, I_{out} = 0.05975 A_{rms} \Rightarrow P_{out-avg} = 0.00404 W, \quad Efficiency = 6.98\%$$

8 Ohm

$$V_{in} = 8 V_{pp}, I_{in} = 0.02311 A_{rms} \Rightarrow P_{in-avg} = 0.06535 W$$

$$V_{out} = 0.7775 V_{pp}, I_{out} = 0.03155 A_{rms} \Rightarrow P_{out-avg} = 0.00867 W, \quad Efficiency = 13.27\%$$

#### Trans./Rec. 5N H Magnet Wire

100 Ohm

$$V_{in} = 4.8750 V_{pp}, I_{in} = 0.10981 A_{rms} \Rightarrow P_{in-avg} = 0.18927 W$$

$$V_{out} = 4.1250 V_{pp}, I_{out} = 0.01420 A_{rms} \Rightarrow P_{out-avg} = 0.02071 W, \quad Efficiency = 10.94\%$$

8 Ohm

$$V_{in} = 5.3250 V_{pp}, I_{in} = 0.10343 A_{rms} \Rightarrow P_{in-avg} = 0.19473 W$$

$$V_{out} = 1.8438 V_{pp}, I_{out} = 0.07394 A_{rms} \Rightarrow P_{out-avg} = 0.04820 W, \quad Efficiency = 24.75\%$$

#### Trans.(1)/Rec. 10N H Copper Hook Wire

8 Ohm

$$V_{in} = 8 V_{pp}, I_{in} = 0.02240 A_{rms} \Rightarrow P_{in-avg} = 0.06337 W$$

$$V_{out} = 1.2250 V_{pp}, I_{out} = 0.03751 A_{rms} \Rightarrow P_{out-avg} = 0.01624 W, \quad Efficiency = 25.63\%$$

#### Trans.(2)/Rec. 10N H Copper Hook Wire

8 Ohm

$$V_{in} = 4.7120 V_{pp}, I_{in} = 0.1105 A_{rms} \Rightarrow P_{in-avg} = 0.18409 W$$

$$V_{out} = 2.475 V_{pp}, I_{out} = 0.10553 A_{rms} \Rightarrow P_{out-avg} = 0.09234 W, \quad Efficiency = 50.16\%$$

Trans./Rec. 5N H Tinned Copper Bus

8 Ohm

$$V_{in} = 3.1025 V_{pp}, I_{in} = 0.09288 A_{rms} \Rightarrow P_{in-avg} = 0.09893 W$$

$$V_{out} = 0.3900 V_{pp}, I_{out} = 0.00442 A_{rms} \Rightarrow P_{out-avg} = 0.00061 W,$$

Efficiency = 0.62%

Trans./Rec. 5N H Copper Wrap Wire

8 Ohm

$$V_{in} = 8 V_{pp}, I_{in} = 0.08322 A_{rms} \Rightarrow P_{in-avg} = 0.23538 W$$

$$V_{out} = 1.7438 V_{pp}, I_{out} = 0.07005 A_{rms} \Rightarrow P_{out-avg} = 0.04319 W,$$

Efficiency = 18.35%

**Data**

The table below shows the powers and efficiencies given by the various coil configurations.

Table 2: Coil Powers and Efficiencies

Coil	Resistance (Ohms)	Pin-avg(W)	Pout-avg(W)	Efficiency (%)
Trans./Rec. 20N V Magnet Wire	1	0.03224	0.00145	4.50
	8	0.04336	0.00917	21.15
Trans./Rec. 10N V Magnet Wire	1	0.05784	0.00404	6.98
	8	0.06535	0.00867	13.27
Trans/Rec. 5N H Magnet Wire	100	0.18927	0.02071	10.94
	8	0.19473	0.04820	24.75
Trans.(1)/Rec. 10N H Copper Hook Wire	8	0.06337	0.01624	19.36
Trans.(2)/Rec. 10N H Copper Hook Wire	8	0.18409	0.09234	50.16
Trans./Rec. 5N H Tinned Copper Bus	8	0.09893	0.00061	0.62
Trans./Rec. 5N H Copper Wrap Wire	8	0.23538	0.04319	18.35

With the horizontal copper hookup wire system giving the best efficiencies, some range tests were done to give an idea on how far the range of the two coils can



be stretched. Figure 6 and 7 below show tests of efficiency vs. distance for tests involving the horizontal copper wire coils.

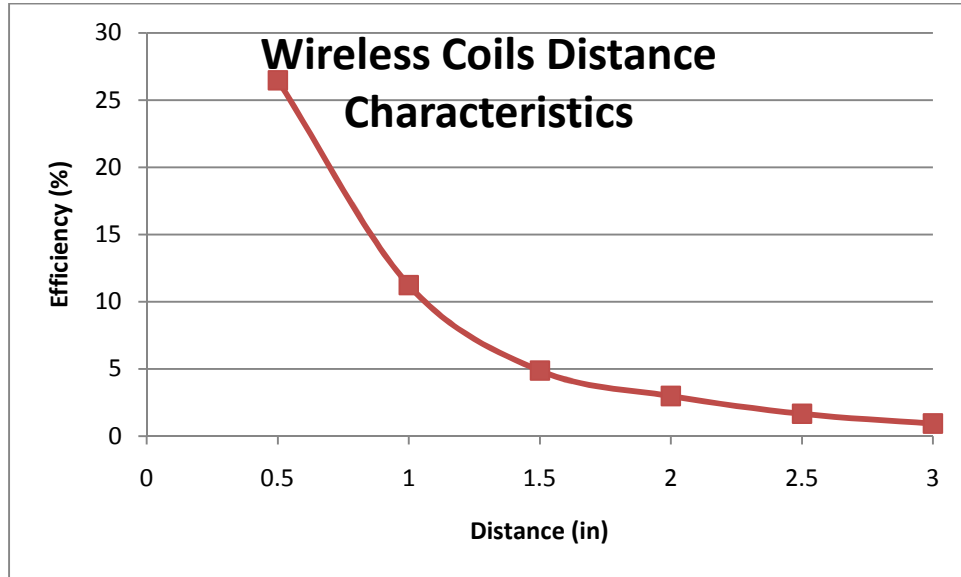


Figure 6: Distance characteristics of the Trans.(2)/Rec. H Hook Wire System

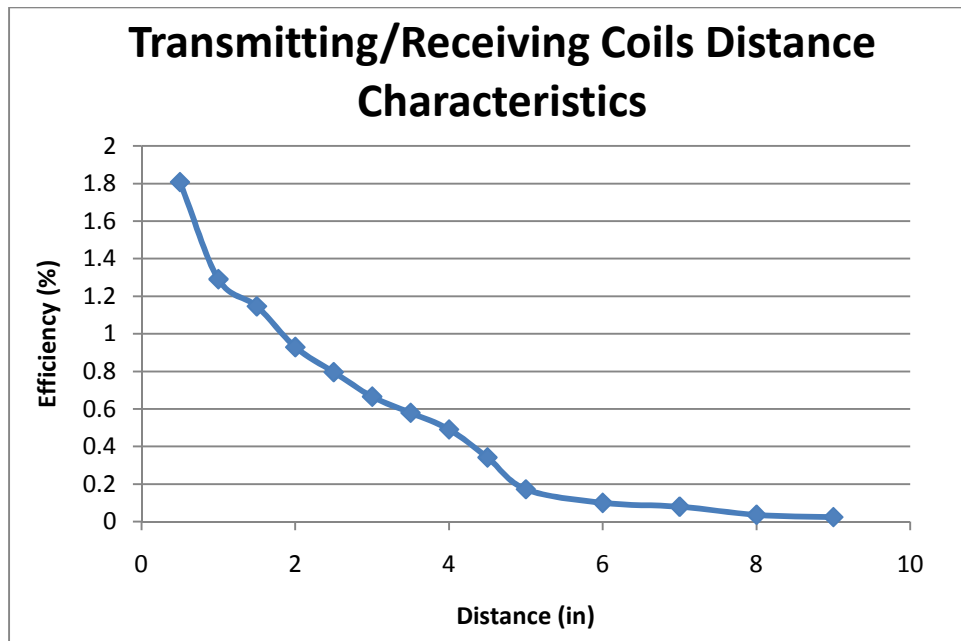


Figure 7: Distance characteristics of the Trans.(2)/Rec. H Hook Wire System

## **Results**

In lab, the coils did not test as well as expected. It was especially noticeable when pairing the transmitting coils with the receiving coils, where the efficiency dipped greatly. Even the highest efficiency obtained was less than the standard 70%, obtaining only up to 50%.

Although the insulated wrapping wire provided good results, and had potential to give good quality factors, the material felt too fragile and thin. It doesn't seem to be smart to use it, especially in higher power situations. Either way, the copper hookup wire provided better results under the same conditions. The tinned copper bus wire also had slightly better L and R values than the hookup wire, but didn't seem to work to transfer wireless energy. The four-coil system also did not live up to its name, testing worse than the hookup wire coils. This could have also been caused by the material, since the similar configurations of magnet wire coils also tested worse than the hookup wire coils.

## **Component Testing**

Some additional testing was done on equipment that can be used for future construction of a charger for a car. A 12V DC to AC inverter and AC to DC converter were tested to measure efficiency and reliability. With the car battery connected to the inverter, attached to the converter, charging the phone, the phone would charge. The system was then taken into a lab, and the inverter was connected to a power supply which provided 12V. The output of the converter was connected to

the phone to charge it once again. The results of the inverter/converter system measurements are shown below:

Figure 8 shows a diagram of the connected components below:

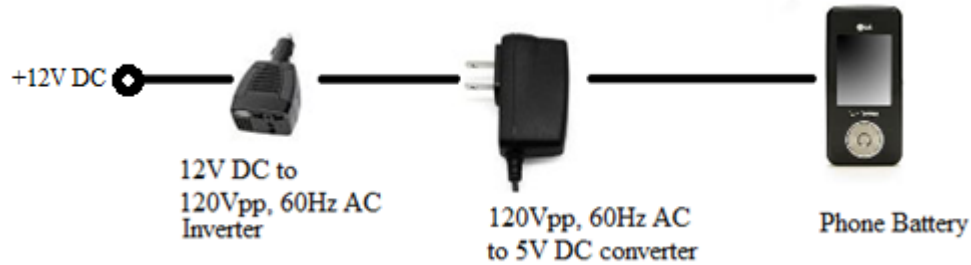


Figure 8: Inverter/Converter Component Diagram

I connected the above and measured  $P_{in}$  and  $P_{out}$ .

$$P_{in} = 12V_{DC} * .530A_{DC} = 6.36 \text{ W}$$

$$P_{out} = 5V_{DC} * .7A_{DC} = 3.5 \text{ W}, \quad \text{Total Efficiency} = 55\%$$

I then measured the output of the inverter using a multimeter.

$$\text{Inverter output} - V = 138 \text{ V}_p, I = .04597 \text{ A}_{rms}, P = 4.4858 \text{ W}$$

$$\text{Inverter efficiency} = 4.3858 \text{ W} / 6.36 \text{ W} = 68.96\%$$

$$\text{Converter efficiency} = 3.5 \text{ W} / 4.3858 \text{ W} = 79.80\%$$

## CONCLUSIONS AND RECCOMENDATIONS

The wireless energy transfer method that was created gave results that were lower than the Qi power requirements. There are several complications that make the system difficult to build.

### Coils

The wireless coils are the main key to the whole system. Making the goal of a 70% efficient wireless power transfer with the distance of 1 foot between the transmitting and receiving coil did not come to fruition. Although there were some good experiments dealing with coils of similar size, in any case where the coil ratio was 0.3, the efficiency decreased. This was unfortunate, since that coil ratio seemed to be usable based on Figure 4. The only positive outcome of using a larger transmitting coil is found when the distance is increased, and the voltage takes a lot longer to fall to zero volts. Further testing could provide a transmitting coil and receiving coil that communicate well together, and thereby providing a coil system that can provide some distance in between each coil, and still maintaining a good efficiency. Realistically, with a transmitting coil with a length of 7.5 in, the distance in between the coils while maintaining a usable efficiency would be about 3 in.

## **Frequency**

There is also a problem with the inductance and resistance values of the coils. Although most of them provided a reasonable quality factor in the lab, the coils would have a lower quality factor when the frequency is changed to the 60-600Hz area. With 60 Hz being the value of frequency usually found in AC plugs in the US, it would be beneficial for inductive coils to be usable at that value. And although a frequency multiplier can be used to increase the frequency, the multiplier to get a 60 Hz wave to the 50000 Hz area would be about 800, which is difficult to execute. A simple way to create the AC signal would be to use the inverter to power a function generator. Unfortunately, this will decrease the efficiency even more. Testing different materials for their large inductance values, while maintaining a low resistance, could be beneficial in the future to increase the quality factor at all frequency values.

## **Power Inverting/Converting**

If using the car battery to charge, the system needs to convert from the DC to AC in order to transfer the electricity wirelessly, which lowers the efficiency of the system. Also, the AC signal has to be converted back into DC in order to charge the battery in the phone, reducing the efficiency even more. The fact that the inverter/converter system itself had such a low efficiency did not help the entire system at all. Since the inverter output was  $138V_p$  instead of  $120V_p$ , this may have also decreased the converter efficiency. A better inverter may provide for a better

inverter/converter system, and testing can be done to see if a better input signal to the converter would help its own efficiency. This will help the entire system with the wireless energy transfer system incorporated to it, since it will help improve the total system efficiency.

With these problems amended, the wireless energy charger will be able to be made, and also be useful. Until then, these problems are great and stand in the way of the charger. The wireless energy technology can be used for other useful projects and charging systems.

## REFERENCES

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## **APPENDIX A**

### **ABET Senior Project Analysis**

#### **Summary of Functional Requirements**

The Wireless Energy Transfer coils are capable of taking in an AC waveform and transferring the energy wirelessly through inductive coupling.

#### **Primary Constraints**

The primary constraint of the coils was the size of the smartphones that were the target for charging. The receiving coil could not be larger than the size of the phone, so it must be made to the same size. The use of wireless power also made it necessary to use AC, which affected the circuits around it. Working with AC made the project the most difficult. It was the main cause of most of the efficiency losses and problems.

#### **Economic**

The original estimated cost of component parts was \$106.63, which was actually higher than the actual final cost of the parts which was \$88.82. This was mostly due to the fact that some of the materials, that were originally planned to be used, were not needed. Some additional equipment costs were needed for wireless energy transfer coil testing, which helped find the best coil material and

configuration. The original estimated development time was 8 weeks, which was much less than the actual 14 week development time that the project required.

### **Commercial Prospects**

If a wireless energy transfer car charger was manufactured on a commercial basis, the estimated number of devices sold per year would be around 50,000 units since it is a luxury item. The estimated manufacturing cost for each device would be about \$80.00, and could sell for \$110.00 per device. Based on these figures, the estimated gross profits would be \$1.5 million per year. With a low chance of component breakdown in the system, the estimated user cost for device maintenance would be \$10.00 per year.

### **Environmental**

The use of the car battery which uses gasoline to charge is not that beneficial to the environment as other forms of charging, but this problem could be remedied with applications in electric or hybrid cars. The electric cars would use alternate forms of power generation besides gasoline, and hybrid cars would use less gasoline than normal cars.

### **Manufacturability**

The manufacturing of wireless coils should be a relatively easy process, as well as soldering the wires of the circuits together. The whole process can be done

either manually or mechanically. Most of the rest of the process of putting the system where it is needed is done by the user.

### **Sustainability**

Since a completed device only serves to charge a phone, there are very few issues to worry about when maintaining it. The only concerns come from errors in the circuit that can be remedied by an auto repair shop. The sustainability of this system is lower, since this is a system for charging, which depends on efficiency for sustainability. The efficiency of this system is sacrificed for practicality, and so it is not as sustainable as a 100% efficient charging system. Any upgrades in the efficiency of the coils or inverters/converters will improve the sustainability of the project. The only problems with upgrading the design are the limits of the technology.

### **Ethical**

This system does not interfere with any ethics since the project will behave in a safe and professional manner. The ethics of “stealing” the idea of wireless energy is fine, since people are allowed to use basic ideas to carry out their project.

### **Health and Safety**

Using magnetic fields to transfer energy is safe to most people, as magnetic fields have no known interference to the normal human body. MRI machines use

much stronger magnetic fields on people with no problems. The magnetic field that the coils create pales in comparison to a MRI scan. People with other materials inside them, such as pacemakers, on the other hand may have a problem though, so there would be some sort of safety check to go through before you buy this product so nobody is harmed.

### **Social and Political**

This would have an excellent social impact on our world. The use of this system in a car will get people questioning what it is, and more people will learn more about wireless energy and how practical it is. There aren't that many political viewpoints about this system, since wireless energy transfer is a relatively new technology on the market.

### **Development**

While creating the project, the amount of knowledge on the internet greatly helped with learning new technologies. Coupled with the basic knowledge of circuits, it was only a matter of combining various technologies to create a final concept.

## APPENDIX B

### Equations

#### DC Power:

$$P = V \times I$$

#### AC Power:

$$P_{avg} = V_{rms} \times I_{rms}$$

$$V_{rms} = \frac{V_p}{\sqrt{2}}$$

$$V_p = \frac{V_{pp}}{2}$$

#### Power Efficiency:

$$Efficiency = \frac{P_{out}}{P_{in}} \times 100$$

#### Frequency:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

#### Capacitance:

$$C = \frac{1}{4\pi^2 f^2 L}$$

**Quality Factor:**

$$Q = \frac{\omega L}{R}$$

## APPENDIX B Cont.

## Schematic

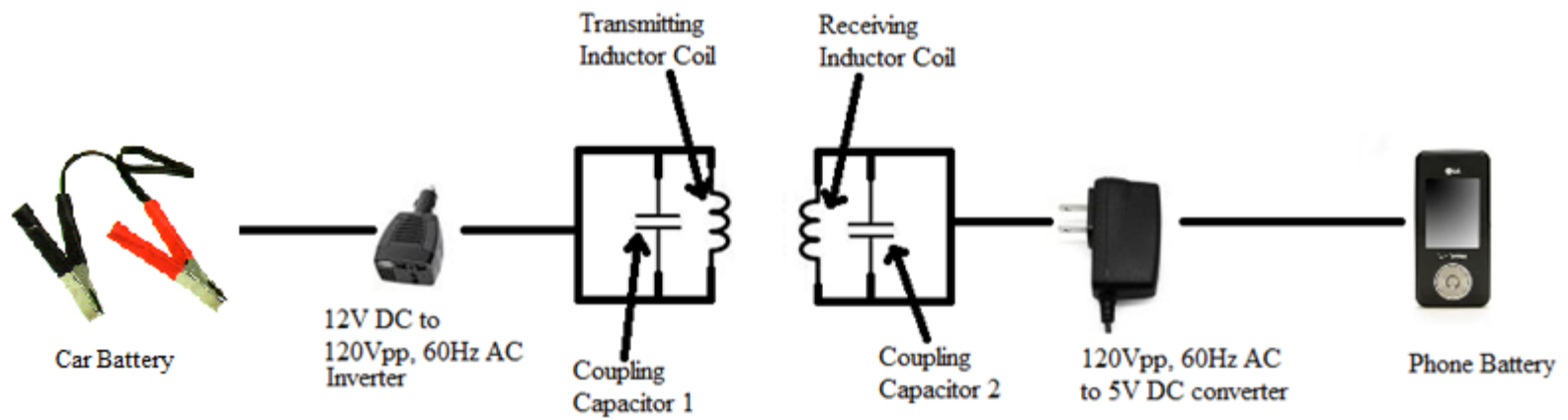


Figure 9: Possible Wireless Energy Charger using Wireless Energy Technology

## APPENDIX C

### Parts List and Cost

Table 3: Parts and Cost

Item	Cost
6 Spools Enameled Magnet Wire	\$19.26
4 Spools Copper Hookup Wire	\$12.44
1 Spool Tinned Copper Wire	\$3.22
1 Spool Copper Wrapping Wire	\$2.92
Resistors	\$7.24
Capacitors	\$14.97
12V DC-AC inverter	\$58.03
AC- 5V DC converter	\$16.88
Labor(14wk*10hr/wk*10\$/hr)	\$1400.00
<b>Total</b>	<b>\$1534.96</b>



## APPENDIC C Cont.

## Timeline of Tasks and Milestones

